# 3. RESULTS

*CRWMS Analysis and Logistics Visually Interactive Model* (CALVIN) Version 2.0 (CRWMS M&O 1999a) was used to generate the waste streams, by cask type, for this analysis. The fuel discharge database and the individual pool cask assignments were updated with the latest information, and the model was run using the assumptions described in Section 2.

The results are provided in two parts. Sections 3.1-3.3 provide data that is independent of the fuel selection process (physical characteristics, handling interfaces, and cask systems). Section 3.4 provides data that is affected by the fuel selection process. This includes throughput related data that describes variations in transportation cask arrivals (number and type) and quantity of assemblies by type. Whereas providing age and heat information implies a knowledge of fuel selection that does not currently exist, the large variation in the results provide for a stringent requirement that ensures a highly flexible system. The design data provided in Section 3.4 was selected because it provided the most limiting requirements from all of the cases reviewed while still being realistic.

This section provides an overview of the design basis waste input. More detailed design basis information is provided in the Appendices. In addition to the normal conditions presented, it is recognized that there will be off-normal conditions and events that need to be accommodated in the system design. These events, because they are uncommon, are discussed in Section B.1.4.

## 3.1 COMMERCIAL SPENT NUCLEAR FUEL PHYSICAL CHARACTERISTICS

Physical characteristics of the CSNF assemblies include length, cross-section, weight, and cladding, as reported by utilities through the RW-859 surveys or as provided by commercial vendors. In addition, they also include associated hardware and handling interfaces. Table 3 summarizes BWR assembly dimensions and weights by related groups, while Table 4 provides similar information for PWRs. Supporting detail, including figures, can be found in Appendix B.

Table 3. Bounding Design Basis Dimensions for BWR Assemblies [a]

| Assembly Group | Design Basis Length (inches) | Design Basis Cross-Section (inches) | Primary Cladding | Design Basis Weight (pounds) | Percent of Total BWR Assemblies | Total BWR Assemblies |
|---|---|---|---|---|---|---|
| Big Rock Point | 81.6 – 84.8 | 6.50 – 7.21 | Zircaloy – 2 | 457 – 591 | < 1 | 524 |
| Misc. Shutdown Reactors [b] | 95.0 – 141.4 | 4.00 – 6.31 | Zircaloy – 2 [c] | 276 – 480 | 1 | 1,615 |
| GE BWR/2,3 and 4,5,6 | 171.0 – 178.0 | 5.24 – 6.07 | Zircaloy – 2 | 556 – 725 | 99 | 164,800 |
| All BWR Assemblies | 81.6 – 178.0 | 4.00 – 7.21 | | 276 – 725 | 100 | 166,939 |

NOTES: [a] Summarized from Tables B-1, B-3, and B-5 in Appendix B.
[b] Includes Dresden 1, Humboldt Bay, and La Crosse.
[c] LaCrosse cladding is 348H stainless steel.

Table 4. Bounding Design Basis Dimensions for PWR Assemblies [a]

| Assembly Group | Design Basis Length (inches) | Design Basis Cross-Section (inches) | Primary Cladding | Design Basis Weight (pounds) | Percent of Total PWR Assemblies | Total PWR Assemblies |
|---|---|---|---|---|---|---|
| Misc. Shutdown Reactors [d] | 111.7 – 140.2 | 6.27 – 8.60 | 304 Stainless Steel [f] | 437 – 1612 | 2 | 2,460 |
| Westinghouse, B&W, and others [b] | 146.0 – 173.5 | 7.76 – 8.64 | Zircaloy – 4 | 1096 – 1705 | 84 | 105,500 |
| CE 16 x 16 and South Texas [c] | 176.8–201.2 [e] | 8.03 – 8.53 | Zircaloy – 4 | 1430 – 1945 | 14 | 16,900 |
| All PWR Assemblies | 111.7 – 201.2 | 6.27 – 8.64 | | 437 – 1945 | 100 | 124,860 |

NOTES: [a] Summarized from Tables B-2, B-4, and B-6 in Appendix B.
[b] Includes two B&W classes, CE 14 x 14, three Westinghouse classes, Fort Calhoun, Palisades, and St. Lucie 2.
[c] Includes CE 16 x 16, CE System 80, and South Texas.
[d] Includes Haddam Neck, Indian Pt. 1, San Onofre 1, Yankee Rowe.
[e] Without inserted control-rod assemblies, the CE 16 x 16 and CE System 80 assembly dimensions should not exceed 180.1 inches even with dimensional adjustments for irradiation growth, thermal expansion, and manufacturing tolerances.
[f] Yankee Rowe cladding is Zircaloy – 4.

### 3.1.1 Cladding

Cladding is predominantly but not exclusively Zircaloy (see Tables 3 and 4 for summaries and Tables B-7 and B-8 in Appendix B for details). Collectively, existing and projected discharged assemblies segregate as shown in Table 5.

Table 5. Cladding Summary By Fuel Type

| CLADDING | PWR | BWR |
|---|---|---|
| Zircaloy | 98.5% | 99.8% |
| Stainless Steel | 1.5% | 0.2% |

According to the Characteristics Data Base (CDB) (DOE 1987, Appendix 2A), BWR assemblies have Zircaloy-2 cladding, while PWR assemblies use Zircaloy-4. Reactors using assemblies with almost exclusively stainless steel (SS) cladding include the following:

- LaCrosse (348H stainless steel)
- Haddam Neck and San Onofre 1 (304 stainless steel)
- Indian Point 1 (304 stainless steel)

- Yankee Rowe has 76 assemblies (304 stainless steel) remaining, which did not get reprocessed following its transition to Zircaloy cladding.

Some assembly classes have a small number of assemblies (usually in the 1-10 total range) that are prototypes or lead test assemblies with cladding distinctly different from the others in that class (i.e., stainless steel cladding instead of Zircaloy). Changes away from zirconium-based cladding are not anticipated. However, ongoing trends toward higher burn-ups and increased cycle durations are leading to changes away from the use of Zircaloy-4 in PWRs in order to improve the corrosion characteristics of zirconium-based cladding. Since 1993, for example, Westinghouse Electric Corporation customers have been progressively increasing the use of zirconium-niobium alloy (ZIRLO) (1 percent Nb, 1 percent Sn, 0.1 percent Fe), such that now virtually all Westinghouse fabrication of domestic PWR fuel uses ZIRLO cladding (Telephone conversations with Mr. George Sabol, Westinghouse-Pittsburgh, and Mr. William Whitehead, Westinghouse-Columbia, September 1, 1999).

### 3.1.2 Assembly Handling Interfaces

Assembly handling differs between BWRs and PWRs. All BWR assemblies have a permanently attached U-shaped fixture at the top of the assembly, with assembly identification numbers located on the upper one-third of the U-shaped fixture (see Appendix B, Section B.1.3). The handling of PWR assemblies requires the use of grappling devices that generally grip the upper end fitting from the inside, with the added complication that the top of the assembly may contain a control-rod assembly, an absorber-rod assembly, or a plugging device (e.g., a thimble plug). These grappling devices are specific to the design and the fuel fabricator, and should be purchased from the fuel fabricator. There are eight groupings of PWR handling geometries (see Appendix B, Section B.1.3). Specific handling interfaces are to be verified (TBV). PWR assembly identification numbers are generally located on the face of the top nozzle or upper end fitting.

## 3.2 COMMERCIAL SPENT NUCLEAR FUEL REQUIRING CANISTERIZATION IN DISPOSABLE CANISTERS

There are 265 single-element-size canisters currently in inventory, subdivided into 145 containing SNF, 101 containing only nonfuel components, and 19 containing debris with a mixture of SNF and nonfuel components. At least 45 of these canisters fall outside the dimensional envelope that bounds all intact CSNF assemblies (minimum length of 81.6 inches, maximum length of 201.2 inches, minimum cross-section of 4 inches x 4 inches, and maximum cross-section of 8.64 inches).

The projected number of single-element-size canisters is shown below.

Table 6. Breakdown of Single-Element-Size Canisters

| Number of Canisters | Type of Canisters |
|---|---|
| 500 - 1,950 (assume 1,100) | Existing failed SNF that must be canistered prior to shipment |
| 1,000 | Projected failed assemblies (see Appendix C, Section C.1.2.2.2) |
| 300 | Material currently stored at utility sites in "baskets" |
| 4,000 | Non-fuel components (less if placed into larger canisters) |
| **6,400** | **Total** |

Additional details on the content of the above canisters are provided in Appendix C.

As noted earlier, it has been assumed that single-element-size canisters will have cross-sectioned dimensions greater than or equal to 4 inches by 4 inches (or diameters $\geq$ 4 inches), and less than or equal to 9 inches by 9 inches (or diameters $\leq$ 9 inches). Thus, all of the canistered fuel has been treated effectively the same as uncanistered fuel, and is implicitly commingled with the uncanistered fuel as opposed to disposed in waste packages dedicated to canistered SNF. It is noted that the canisters of nonfuel components do not have an MTU equivalent. Therefore, the nonfuel canisters do not currently have any position in the delivery queue. Additionally, it has not been determined if all of this material requires geologic disposal, nor how those requiring repository disposal will be packaged. The current projections do not include the pickup, transport, or disposal of these canisters of nonfuel components. In general, it is expected that this material will be picked up in normal transport casks, possibly with special baskets, after SNF has been removed.

## 3.3 CASK AND CARRIER SYSTEMS

Design basis cask/carriers systems include legal-weight truck casks and rail casks loaded either on railcars or heavy-haul trucks. Bounding cask physical characteristics for CSNF transportation cask types projected to be received at the MGR are summarized in Table 7.

Table 7. Design Basis Cask Exterior Bounding Dimensions

| Cask Physical Characteristics | | BWR | | PWR | |
|---|---|---|---|---|---|
| | | Truck [a] | Rail | Truck [a] | Rail |
| With trunnions, and impact limiters | Length (inches) | 245 | 327 | 234 | 340 |
| | Diameter (inches) | 90 | 140 [d] | 90 | 140 |
| With trunnions, w/o impact limiters | Length (inches) | 200 | 233 | 200 | 233 |
| | Diameter (inches) | 48 | 103 | 48 | 103 |

Table 7. Design Basis Cask Exterior Bounding Dimensions (Continued)

| Cask Physical Characteristics | | BWR | | PWR | |
|---|---|---|---|---|---|
| | | Truck [a] | Rail | Truck [a] | Rail |
| Without trunnions or impact limiters | Length (inches) | 200 | 233 | 200 | 233 |
| | Diameter (inches) | 48 | 99 | 48 | 99 |
| Weight (tons) | | 26.8 | 150 [b] | 27.1 | 150 [b] |
| Average Assembly Heat (watts) [c] | | 235-1,100 | 235-2,400 | 600-2,500 | 235-6,000 |

NOTES: [a] Includes both the small (1 PWR / 2 BWR) cask and the large (4 PWR / 9 BWR) cask.
[b] Includes 20 percent design margin for maximums over maximum projected cask weights.
[c] Inverse correlation between cask average assembly thermal output and number of assemblies transported.
[d] TN-68 storage cask is docketed with the NRC for a 10 CFR Part 71 (Transportation) license, but this license has not yet been issued. TN-68 has a diameter (with trunnions and impact limiters) of 144 inches.

A table providing the dimensions of individual cask types is included in Appendix D, along with references to the documents used to develop the table. Bounding characteristics for cask carrier systems are provided in Table 8.

Table 8. Design Basis Cask Carrier System Bounding Physical Characteristics

| Carrier Physical Specifications [a] | Rail Car | Heavy-Haul Truck | Legal-Weight Truck |
|---|---|---|---|
| Maximum Length (feet) | 67.5 | 220 [b] | 59.75 |
| Maximum Width (inches) | 140 [c] | 168 | 96 |
| Maximum Height (inches) | 181 | 168 | 162 |
| Total Weight (pounds) | 263,000 (4-axle car)<br>526,000 (8-axle car) | 502,000 | 80,000 |
| Maximum Per-Axle Gross Weight (pounds) | 65,750 | 40,560 (TBV) | 17,000 |

SOURCES: [a] Physical parameters taken from reference CRWMS M&O 1998b, except for heavy-haul truck maximum length.
[b] Parameter taken from reference PTG 1997.
[c] TN-68 will require a rail with a width of 144 inches (assuming it is licensed for transport).

## 3.4 CASK AND ASSEMBLY ARRIVAL DATA

Tables 9 through 14 provide a summary of the cask arrival results. Detailed data is provided in Appendix E. Table 9 provides the average and maximum cask arrivals grouped into five time periods (initial ramp up, ramp down, and 10-year increments in-between). Note that in a few specific cases, a mix of CSNF classes (e.g., at San Onofre) may be included in any cask or DPC shipment.

Table 9. Cask Shipments by Transportation Mode

| Year | Annual Average [a] | | | | Annual Maximum [a] | | | |
|---|---|---|---|---|---|---|---|---|
| | Truck | UCF Rail | DPC Rail | Combined [b] | Truck | UCF Rail | DPC Rail | Combined [b] |
| 2010-2014 | 120 | 160 | 30 | 300 | 220 | 340 | 40 | 580 |
| 2015-2024 | 90 | 350 | 60 | 500 | 230 | 380 | 110 | 620 |
| 2025-2034 | 10 | 230 | 150 | 390 | 40 | 330 | 240 | 450 |
| 2035-2039 | 0 | 60 | 260 | 310 | 0 | 70 | 260 | 320 |
| 2040 | 0 | 40 | 140 | 180 | 0 | 40 | 140 | 180 |

NOTES: [a] Numbers have been rounded up to the nearest 10 casks.
[b] Combined is the maximum combined number of casks to arrive in any 1 year, not the sum of the maximum values shown in the table.

Table 10 displays the maximum quantity of assemblies expected to arrive within any given year, by type.

Table 10. Summary of Maximum Annual Assembly Arrivals

| | BWR | PWR | Combined [a] |
|---|---|---|---|
| Maximum [b] | 7,800 | 5,000 | 11,500 |

NOTES: [a] Combined is the maximum total number of assemblies arriving in any 1 year, not the sum of the maximum values shown in the table.
[b] Numbers have been rounded up to the nearest 100 assemblies.

While the total number of assemblies arriving did not change, there was a small variation in the number of assemblies arriving in a given cask type for the various cases; however, it was within the margin of uncertainty. The assembly totals are shown in Table 11.

Table 11. Total Assembly Arrivals by Cask Contents

| Cask Contents | Assemblies [a] |
|---|---|
| Uncanistered SNF | 156,400 |
| DPCs | 135,300 |

NOTE: [a] Numbers rounded to the nearest one hundred.

The Waste Package Operations and Performance Assessment Operations organizations require assembly characteristics information. As all CSNF is to be accepted, the enrichment and burnup characteristics provided in Table 1 apply for all cases. In addition, the age ranges were virtually identical regardless of the fuel selection method examined, with a minimum age of 5 years and a maximum age of 59–61 years. However, there was a considerable difference in the age distribution, as can be seen in Figures 1 and 2. These figures display assembly age for all fuel at arrival at the repository, based on the assumptions provided in Section 2, for Cases B and C.

Tables 12 and 13 show the heat output per assembly for BWR and PWR fuel, respectively. This reflects heat output for the entire waste stream at arrival at repository, based on the assumptions described in Section 2 for Cases A, B, and C. A more detailed breakout is provided in Appendix E for Case B, which was determined to be the most stressing case. The average heat per assembly is approximately 190 and 550 watts for BWR and PWR fuel, respectively. Note that the heats in these tables (and in Appendix E) were generated using the ORIGEN 2-based method. Table 14 provides an estimate of the heat distribution for the 72 TRIGA assemblies, assuming an age at arrival of 30 years. Note that the heat was based on Table 4.4.25 of Volume 2 of the CDB (DOE 1992a), scaled linearly with burnup and assembly/rod weight.

Table 12. Summary Heat Distribution for BWR Fuel (Watts) at Arrival [b]

| Heat Range (Watts/Assembly) | Case A (percent) | Case B (percent) | Case C (percent) | Range [a] (percent) |
|---|---|---|---|---|
| 0 - 49 | 5.6 | 5.6 | 5.2 | 5.2 - 5.6 |
| 50 - 99 | 22.8 | 24.6 | 18.4 | 18.4 - 24.6 |
| 100 - 149 | 15.6 | 16.0 | 21.0 | 15.6 - 21.0 |
| 150 - 199 | 11.8 | 10.9 | 14.2 | 10.9 - 14.2 |
| 200 - 249 | 16.3 | 8.9 | 18.1 | 8.9 - 18.1 |
| 250 - 299 | 9.2 | 10.5 | 13.8 | 9.2 - 13.8 |
| 300 - 349 | 10.6 | 13.3 | 5.8 | 5.8 - 13.3 |
| 350 - 399 | 6.2 | 8.1 | 2.3 | 2.3 - 8.1 |
| 400 - 449 | 1.2 | 1.4 | 0.9 | 0.9 - 1.4 |
| 450 - 499 | 0.4 | 0.5 | 0.3 | 0.3 - 0.5 |
| 500 - 549 | 0.2 | 0.2 | 0.0 | 0.0 - 0.2 |
| 550 - 599 | 0.1 | 0.0 | 0.0 | 0.0 - 0.1 |

NOTES: [a] Column may not add to 100 percent due to rounding.
[b] Based on Origen 2 heat code.

Table 13. Summary Heat Distribution for PWR Fuel (Watts) at Arrival [c]

| Heat Range (Watts/Assembly) | Case A (percent) | Case B (percent) | Case C (percent) | Range [b] (percent) |
|---|---|---|---|---|
| 0 - 99 | 1.0 | 1.0 | 0.9 | 0.9 – 1.0 |
| 100 - 199 | 8.1 | 8.3 | 7.0 | 7.0 - 8.3 |
| 200 - 299 | 16.2 | 17.9 | 13.9 | 13.9 - 17.9 |
| 300 - 399 | 13.9 | 14.8 | 16.3 | 13.9 - 16.3 |
| 400 - 499 | 9.7 | 8.8 | 13.8 | 8.8 - 13.8 |
| 500 - 599 | 9.0 | 7.9 | 13.4 | 7.9 - 13.4 |
| 500 - 699 | 14.4 | 7.6 | 12.7 | 7.6 - 14.4 |
| 600 - 799 | 9.4 | 8.6 | 8.3 | 8.3 - 9.4 |
| 800 - 999 | 12.3 | 14.3 | 8.1 | 8.1 - 14.3 |

Table 13. Summary Heat Distribution for PWR Fuel (Watts) at Arrival (Continued)

| Heat Range (Watts/Assembly) | Case A (percent) | Case B (percent) | Case C (percent) | Range (percent) |
|---|---|---|---|---|
| 1,000 – 1,199 | 2.5 | 6.5 | 2.3 | 2.3 - 6.5 |
| 1,200 – 1,399 | 1.0 | 2.0 | 0.9 | 0.9 – 2.0 |
| 1,400 – 1,599 | 0.6 | 0.5 | 0.5 | 0.5 - 0.6 |
| 1,600 – 1,799 | 0.3 | 0.2 | 0.2 | 0.2 - 0.3 |
| 1,800 – 1,999 | 0.1 | 0.1 | 0.1 | 0.1 - 0.1 |
| 2,100 – 2,199 | 0.0 | 0.0 | 0.0 | 0.0 – 0.0 |
| MOX [a] | 1.4 | 1.4 | 1.4 | |

NOTES: [a] Heat is not calculated for MOX fuel.
[b] Column may not add to 100 percent due to rounding.
[c] Based on Origen 2 heat code.

Table 14. Estimated Heat Distribution for TRIGA Fuel (Watts)

| Heat Range (Watts/Assembly) | Percent of Assemblies [a] |
|---|---|
| 0.00 - 0.09 | 39 |
| 0.10 - 0.19 | 6 |
| 0.20 - 0.29 | 1 |
| 0.30 - 0.39 | 1 |
| 0.40 - 0.49 | 6 |
| 0.50 - 0.59 | 13 |
| 0.60 - 0.69 | 7 |
| 0.70 - 0.79 | 4 |
| 1.10 - 1.19 | 1 |
| 1.20 - 1.29 | 4 |
| 1.40 - 1.49 | 3 |
| 1.50 - 1.59 | 4 |
| 1.60 - 1.69 | 4 |
| 1.70 - 1.79 | 3 |
| 1.90 - 1.99 | 1 |
| 2.20 - 2.29 | 1 |
| 2.30 - 2.39 | 1 |

NOTES: [a] Column may not add to 100 percent due to rounding.

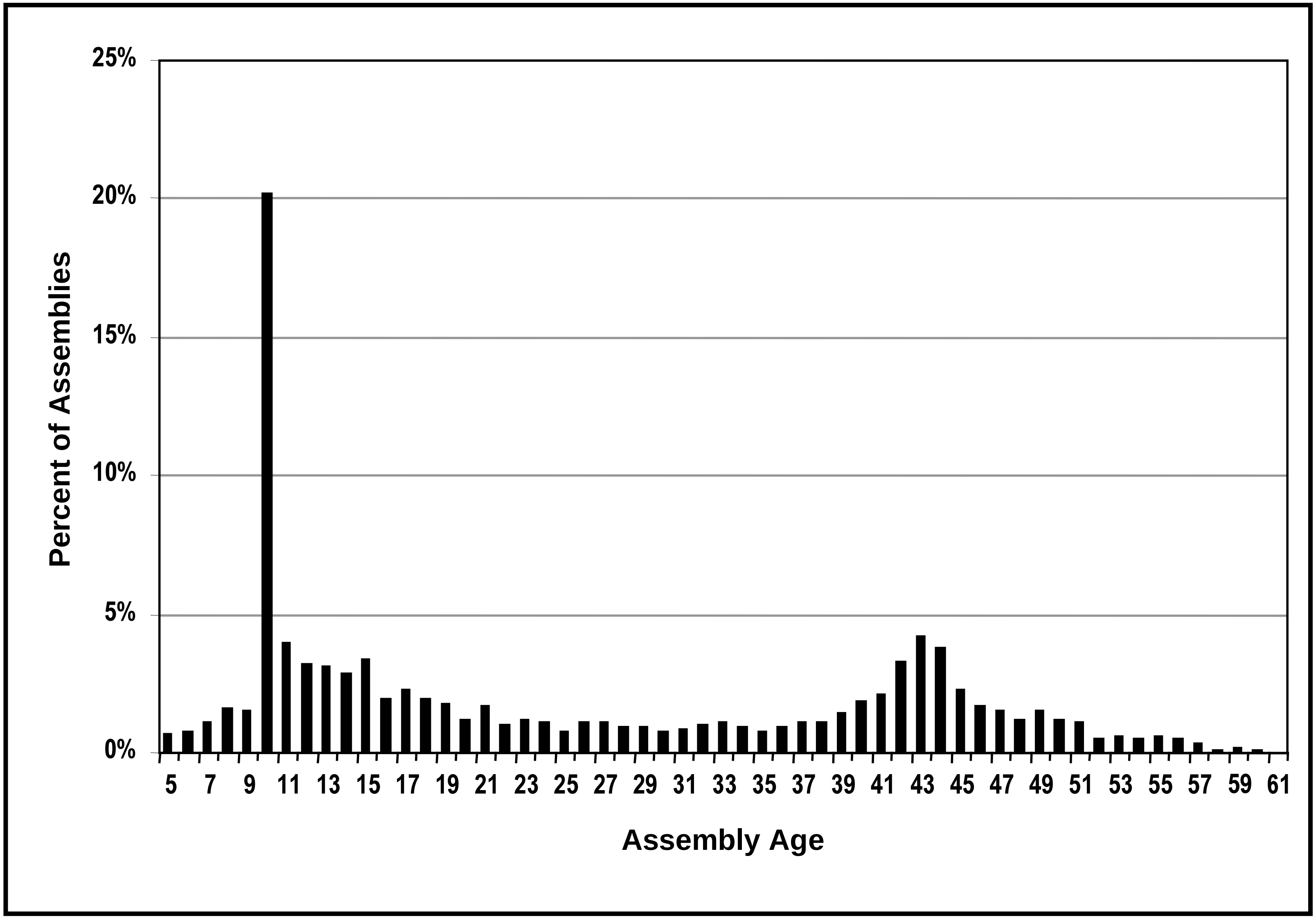


Figure 1. Age Distribution for Case B at Arrival

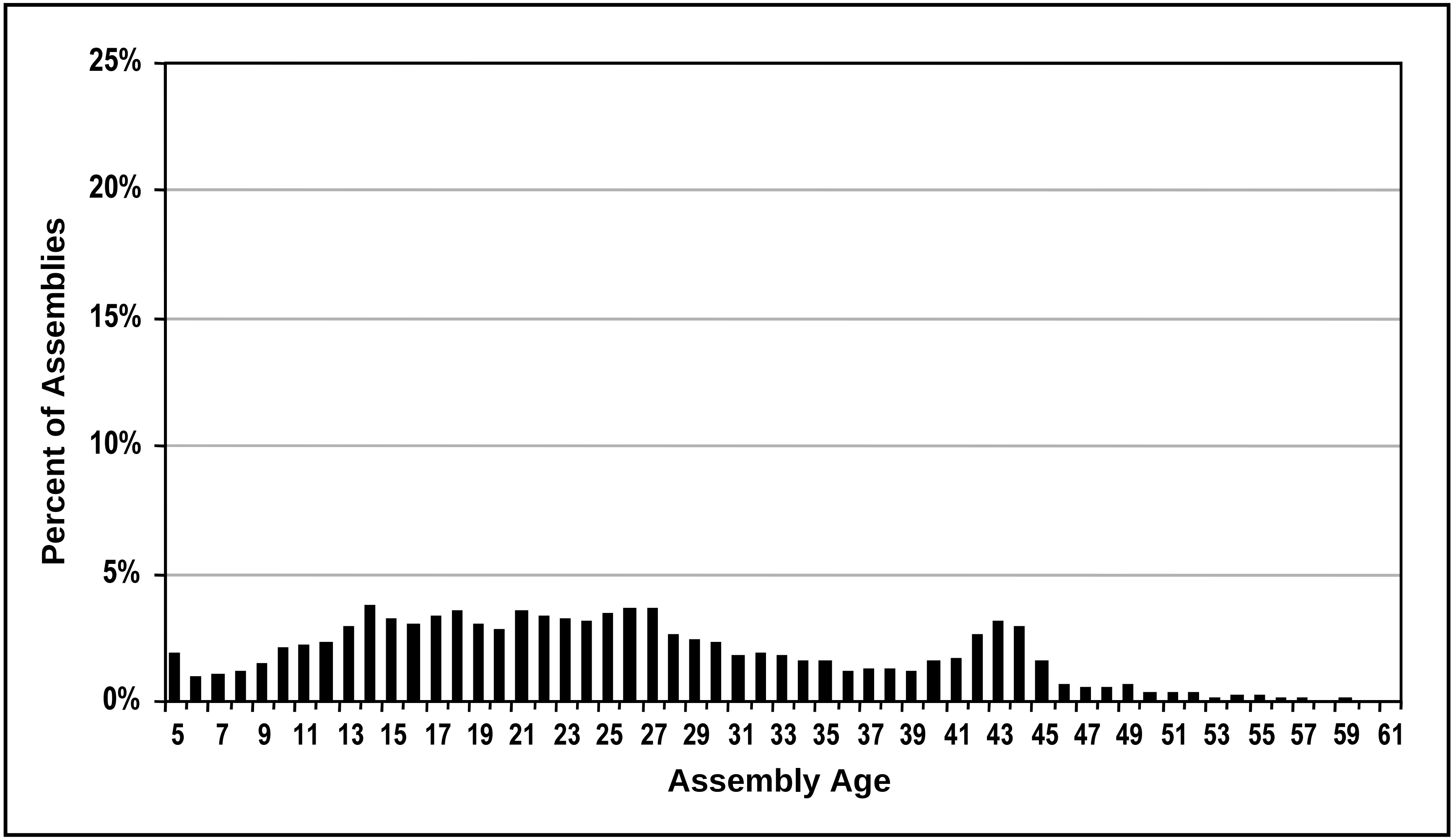


Figure 2. Age Distribution for Case C at Arrival